DUAL SOURCING IN DEFENSE MISSILE PROCUREMENT

Problems in defense procurement have received substantial attention recently, both in the academic and popular press. An often repeated recommendation is that the DoD should increase the use of “competition” in defense procurement. While competition may take many forms (e.g. design competition, competition of major subcontractors, etc.), the most important approach currently being pursued by the Congress is the establishment of “dual sourcing” in production[1]. Sole source procurement is normally the alternative to dual source procurement in the production phase and is generally considered “noncompetitive”, irrespective of competition during the development phase, competition among vendors of high value subsystems (e.g. engines or avionics), or competition from other weapons systems that are substitutes for some range of requirements. Sole source suppliers are generally viewed as behaving much as regulated utilities with analogous economic distortions.

The case for dual sourcing can not be made on purely theoretical grounds. While economists are generally pro competition, most defense sectors are declining cost industries. Dual sourcing would appear to be capable or creating incentives for cost minimization as compared to other contracting methods (with their attendant regulatory apparatus). However, given the declining cost nature of these industries, such incentives would be obtained at the price of incurring increases in underlying economic cost due to foregone scale economies. Further, the government may incur substantial nonrecurring costs in establishing a second source. These two factors tend to make dual sourcing more attractive for systems that have relatively large production runs, and possess proportionally low nonrecurring costs. Tactical missile systems are a class of weapon system that are generally agreed to possess these characteristics.

A number of studies have been done in the past fifteen years on defense competition in general, and dual sourcing in particular (see Hampton[10] for a reasonably complete survey of the literature). Some of these studies have concluded that dual sourcing does lower the price structure of the participating firms in comparison to a sole source procurement environment. Not all of these studies analyzed present value savings, but those that did have concluded that, while the price structure of the supplying firms did decrease, when nonrecurring costs are taken into account, there has been no uniform net savings to the government from pursuing dual sourcing[2]. These studies have used essentially the same data, which came from a variety of defense programs (the majority of which are relatively simple electronic systems[3] from the 1960’s and early 1970’s). It is indicative of the problems in using these data that, although many of these studies use identical data, they reach significantly different conclusions about the efficacy of dual sourcing in many individual cases[4,5]. These data may not be relevant in evaluating the effects of dual sourcing major, non-electronic weapon system because of differences in the way that the DoD acquires major systems and because of differences between electronics and other defense industrial sectors.

Dual sourcing in tactical missiles has been pursued vigorously in the past decade and DoD's tactical missile experience has often been cited as "the" success story in dual sourcing[6]. It is the purpose of this study to assess the economic benefits of recent dual source tactical missile procurements using the negotiated contract prices. This will be done by estimating the probable cost of sole sourcing five contemporary missile systems and comparing these estimated costs with actual cost experienced with dual sourcing each of the systems. All of the programs considered here were procured from a single prime firm for several years (during which time the second source was beginning production) prior to head to head dual source competition. The nonrecurring costs associated with bringing a second on line are included in the cost of the dual source alternative. This analysis does not include either nonrecurring costs of the prime firm, developmental costs (both of which are effectively sunk), additional costs to the government of having two suppliers (such as additional oversight costs), or complications (due to non-identical configurations) in the fielding and maintenance of the items, etc. All of the programs analyzed have either completed production or have but one more production lot remaining. To provide a common basis for comparison, all data in this study is normalized to constant FY 1983 dollars. Nonetheless, if dual sourcing is a cost effective means of acquiring these weapons, the production contract data should show some evidence of the claimed savings.

A familiarity with the broad features of contemporary defense procurement is important for an understanding of the economics of dual sourcing. The paper begins with a brief summary of those features. A model of sole source procurement will be constructed that is similar to the models used by defense cost analysts. The parameters of this model will be evaluated and the implied costs compared with the dual source cost. Finally, as a check on the robustness of the conclusions under differing sole source assumptions, a "worst case" sole source cost function (i.e. the highest cost sole source costs that would normally be expected on such programs) will be constructed. This case is intentionally designed to model the poorest economic performance normally experienced under sole sourcing and will be compared with the achieved dual source costs.

An Overview of the Weapons Acquisition Process

Within defense acquisition, unlike most commercial sectors, the developing agent and the final customer jointly participate in setting both design goals and in the testing and evaluation of technical approaches and prototypes. The development of a new high technology weapon, like a tactical missile, is the result of detailed threat, operational and environmental requirements analysis by the services, engineering development by (possibly several competing) contractors and extensive testing by both the government and the contractor(s). As a result of this process, the government usually acquires rights to the "technical data package" (referred to as the TDP), or the design of the end item. The hardware item may be built by the original developing contractor (using sole source procurement), the winner of a production contract competition (known as "winner take all"), or multiple production contractors (dual source). For reasons of statutory regulation, contracts are normally let for annual lot buys unless a special accommodation is made with the Congress for the authority to enter into a "multiyear contract".

Sole source acquisition of weapons is relatively straight forward. The development phase of sole source acquisition may be competitive; i.e. more than one developing firm. However, the prototypes compete and the winning firm (and its design) is selected for the production contracts. These awards are made on a directed, or noncompetitive basis. Even so, sole source in production does not necessarily imply the absence of competitive pressure. Competition among systems that are imperfect substitutes is quite common, as the recent F-16/F-20 and C-5/C-17 aircraft competition demonstrate.

Under the contracting rules, an individual sole source contract (usually awarded annually, to coincide with the budget cycle) may be awarded only if the government determines that there is only one firm that can perform the projected work, either technically (i.e. no other firm has the ability to do the work), or perform it within the chronological constraints required. A public announcement of the intent to award a sole source contract is made prior to award and other firms are given the opportunity to demonstrate their ability to do the work. The price of a sole source contract is negotiated between the government and the contractor at a "fair and reasonable" level. In practice, price determination is almost based on estimated production cost, even though a fixed price type contract similar to those used in competitive procurements may be used. The negotiations between the contractor and the government for each year's lot are predicated on the historical costs of the previous year's lot and certain, reasonably standard, industrial cost models. The cost data used in these negotiations are generated in a government specified, and monitored accounting framework similar to those imposed on regulated utilities. Profit (i.e. a government payment in excess of documented costs, called “fee”) is allowed the contractor under a set of administrative guidelines whose substantive effect is to determine profit as a fixed percentage of revenue. (A recent change in DoD profit policy will redirect the return on sales orientation of fee determination towards a return on assets criterion, but this change is subsequent to the contracts covered in this study.)

Dual sourcing involves the establishment of two production sources for a single weapon with the annual production divided between the firms primarily as a function of their bids. All competitive procurement need not be dual sourcing, and the principal competitive alternative to dual sourcing is “winner take all” competition; in which a single firm wins an auction (among several firms) for the contract to produce each year’s lot. Due primarily to the difficulties associated with qualifying new production sources (discussed below) , winner take all type competitive acquisitions have been rare in recent major systems[7]. An increasing popular variant of competitive procurement (though not addressed here), is called “teaming”, where two sources co-develop an item and compete for lots in production. Under dual sourcing, the proportion of a annual lot awarded to each firm is referred to as the “split”, and the government typically guarantees a minimum split to each contractor. While both dual sourcing and winner take all contracts are normally “fixed price” arrangements (i.e. like typical commercial contracts) in which little cost reporting or regulation is typically imposed, the government does have access to a firm’s “certified cost and pricing” data from prior contracts when negotiating a new contract. This cost data, due to its sensitive competitive nature, is not generally made available outside the contracting activity that lets the contracts in question.

A dual sourcing acquisition strategy is somewhat more complex than sole source procurement due to the need to ensure that the government receives missiles from both sources that meet the quality standards required. The development phase of a dual sourced missile is generally similar to that of a sole source missile program. When the missile goes into full scale production, the government can use the TDP to initiate a second source. However, steps, known as production vendor “qualification”, to assure that the second source is, in fact, a reliable source of missiles must be taken. The ability of the government to provide the TDP to a production contractor that did not develop the missile and reasonably expect expedient production capability depends on several factors, but the stability of the configuration (i.e. the rate at which the TDP changes) is the most critical consideration. Configurations are constantly changing in response to defects, changes in the availability of raw materials or components, the evolving threat and “value engineering”, or cost reduction. Typically, there are significant changes in the first few production lots. Subsequently, unless there are extraordinary engineering problems, the TDP becomes relatively stable and dual sourcing is feasible. The government will not normally dual source a weapon until after several production lots.

The firm selected to become a second source must win a competition with other firms for the contract to become production qualified. In the tactical missiles field, there are usually two or three firms that compete for the second source qualification contract. Production qualification involves two efforts, the construction by the second source firm of small initial lots of missiles and testing by the government of some of those missiles. At least one, and typically several, “educational buys”, or low rate initial production lots, are made from the second source. These lots are awarded to the second source (prior to competition with the prime firm) and serve to demonstrate that the missiles produced from the second source are adequate, and also provide an opportunity for the firm to apply “producibility” engineering on the production line. The government may sometimes explicitly pay for some of the nonrecurring costs to facilitize the second source in the initial contracts, but the remaining costs are amortized by the firm in a manner analogous to commercial contracts. Missiles usually can not normally be completely evaluated without destructive testing (i.e. discharging the weapon). Therefore, some of the missiles in each educational buys are destroyed in such testing and represent a pure nonrecurring cost to the establishment of the second source. Particularly when there are production quality problems, these testing costs can be considerable. The remaining missiles are inventoried (provided that the testing is successful). Presumably, the production of these missiles prepares the second source for "full and open" competition with the prime source. In tactical missiles, the production qualification process can take up to three years.

After the second source is qualified, the prime and second sources compete for a proportion of the annual lots. The Congress, in each fiscal year’s Authorization bill, specifies the maximum number of missiles that the government has the legal authority to purchase. The firms submit a unit price bid for a set of bids for splits predetermined by the government (i.e. “stepladder bids”). The government evaluates the bids and awards contracts to each contractor, the relative size of which is determined by ‘the bids of each contractor. The relative proportion of the total annual lot going to each contractor is referred to as the “split”. The bids are a sealed, though price data on previously awarded contracts is known. While the firms bid for annual lots, due to lags in contract administration, procuring long lead items and production, generally bids are being prepared while at least one prior year’s lot is in production. A consequence of this sequential bidding arrangement is that firms are able to use available knowledge about the problems that their opponents may be having with current production lots in developing their bidding strategy. Firms may also wish to bid very aggressively on the early production lots in order to gain a “learning curve” advantage over their opponents. Alternatively, a firm may decide that since the government has announced a policy of dual sourcing (hence would find it difficult to not award some missiles to both of the qualified contractors), the firm can do sufficiently well with the “loser’s” share of the split if it does not bid aggressively. If both contractors come to this conclusion, the government may have dual source competition, but for the highest price and the smallest share. Within defense circles, any bidding strategy that deviates from the firm's cost structure is referred to as "gaming". Gaming is not surprising from an economic standpoint (since analogous characteristics are a common feature of oligopolistic models), but it does pose empirical problems when attempting to estimated what a sole source alternative would have cost.

Price determination, in the economist's sense of the term, is difficult to characterize in a dual source environment. It appears to share characteristics of both duopoly disequilibria and cost based pricing. However, dual sourcing does create incentives for cost minimization that are largely absent from sole sourcing. The "price" to the government of creating such incentives is the nonrecurring costs required to establish a second source and the reduced scale economies available in (generally) declining cost industries.

Statement of the Model

The objective of the analysis is to compare the observed costs of dual sourcing with the probable costs of sole sourcing. In simplest terms, the percentage savings from dual sourcing is given by tile following:

$$savings = \left(1 - \frac{TC_{DS}}{TC_{SS}}\right) \times 100 \qquad (1)$$

where:

TC_{SS} - total estimated present value of the cost to the government under the sole source alternative, and

TC_{DS} - total present value of the cost to the government under the dual source alternative.

The numerator of the second term in (1) is the cost to the government actually experienced if the system is dual sourced. Since the dual source costs are observed, TC_{DS} may be calculated directly. Using the term "prime" to refer to the hardware development (and initial production) contractor and "follower" to refer to the second source, this cost may be expressed as:

$$TC_{DS} = \sum_{i=1}^{N} \zeta^{i} \left[C_{P,i} + C_{F,i}\right] \qquad (2)$$

where:

$C_{P,i}$	-	cost to the government of lot i from the prime contractor,
$C_{F,i}$	-	cost to the government of lot i from the follower contractor (including nonrecurring costs),
N	-	the total number of lots purchased, and
ζ	-	discount factor.

The dual source cost must be compared with an estimated sole source alternative's cost to the government of equal benefit (i.e. with the same time stream of inventoried missiles). This cost to the government is estimated by estimating each lot's cost with a "cost function", $C(Q_i,q_i)$ where q_i is the total (i.e. sum of prime and follower) missiles in each lot inventoried and Q is the total prior cumulative quantity for both contractors in lot i. It is important to note that $C(Q_i,q_i)$ is not a cost function in the normal microeconomic sense of the term; it rather is simply the estimated cost to the government of the lot in question. We can not generally obtain true "cost" (in an economic, as opposed to accounting, sense) data on defense programs, so these functions are estimated with price data. Following general defense cost analysis practice, I shall, nevertheless, refer to such data and functions as "cost" related.

Using $C(Q_i,q_i)$, in present value terms. the expression for the present value of the sole source alternative with a benefit to the government equal to the dual source alternative is:

$$TC_{SS} = \sum_{i=1}^{N} \zeta^{i} \; C(Q_i,q_i) \qquad (3)$$

The function $C(Q_i,q_i)$ must be estimated. Estimation of missile cost functions (which, by assumption represent the firm's supply function in a sole source procurement) from a single contractor is a well established discipline within the defense community. These cost functions generally have the two arguments, the cumulative prior production of the missile in question and the amount to be produced in a given lot. Two features characterize missile cost functions; the "progress curve" effect of total cumulative quantity on cost and an output per unit time effect (not unlike a classic firm's supply curve), called a "rate adjustment" effect. This latter effect is always downward sloping since most defense firms operate below capacity.

The progress curve phenomenon (sometimes referred to as the “learning” curve) is a common part of industrial engineering cost analysis in many industrial sectors. Progress curve theory, in the unit formulation[8] states that, holding other factors constant (in particular, production rate), marginal cost declines in a power formulation, or:

$$\frac{\partial C}{\partial x} = F \; x^{-\beta} \qquad (4)$$

where:

x	-	cumulative production unit, and
F, β	-	positive parameters.

Relation (4) is a static formulation, i.e. the progress curve refers to the “learning” that goes on in production regardless of the rate at which items are produced. In addition, unit costs are observed to be sensitive to production rate in the sense of a typical industry short run cost curve. Weapons producers (almost always) operate on the declining portion of their supply curves (per unit time). Defense cost analysts refer to this declining cost curve as a rate adjustment. The functional form of the adjustment is either an harmonic form, that allocates a fixed “overhead burden” over a varying number of units, or the more common power form[9]. The power form is used here and is stated as:

$$\frac{\partial C}{\partial r} = G \; r^{-\alpha - 1} \qquad (5)$$

where:

r	-	rate of production (equal to the lot size in this analysis since annual lots are assumed), and
G	-	a constant, equal to (for convenience):

$$G \equiv -\alpha \; \frac{F}{(1-b)} (1 - q^{-\alpha}) \; \left[(Q+q)^{(1-\beta)} - Q^{(1-\beta)} \right]$$

Integrating (4) and (5) with respect to their variables and using appropriate values for the limits of integration yields the following expression for the cost of each lot:

$$C(Q,q) = \int_{Q}^{Q+q} \frac{\partial C}{\partial x}\, dx + \int_{0}^{q} \frac{\partial C}{\partial r}\, dr \qquad (6)$$

or (including the definition of *G):*

$$C(Q,q) = K\, q^{-\alpha} \left[(Q+q)^{(1-\beta)} - Q^{(1-\beta)} \right] \qquad (6')$$

where K is a parameter equal to F/(1-β).

Relation (6') is the sole source cost function used in the remainder of the analysis. It has three parameters, α, β, and K that must be estimated for each sole source case examined.

Estimation of Sole Source Cost Function Parameters

There have been five tactical missile programs since the mid-1970's, the Sparrow AIM-7F, Sparrow AIM-7M, Sidewinder AIM-9L, Sidewinder AIM-9M and Tomahawk. The Tomahawk is excluded from consideration here since the number of different basing modes, guidance systems and warheads substantially complicates the structure of a cost function required for that program and since (unlike the other programs considered) the program is only about half through its production run. This last factor would necessitate the estimation of both sole source and dual source cost functions for extrapolation through remaining the production run. Further details on each of the programs considered is contained in Appendix A.

Since sole sourcing did not actually occur on any of these programs, i.e. it was intended that they be dual sourced from initial production planning on, (with the possible exception of the AIM-7F) estimating the costs of a sole source program is necessarily problematic. The sole source estimation problem is compounded by the number of lots for each of the programs. Table 1 summarizes the lot data available for the these dual sourced missile programs. The traditional assumption in previous studies[10] has been to assume that the lots produced by the prime firm prior to head to head competition with the second source are representative of the sole source cost structure. Hence the estimated sole source cost curve is generally based on data from the very few lots prior to the advent of competition. As Table 1 shows, this implies that the sole source curve is estimated with either little or no degrees of freedom. This procedure does closely follow the way in which government cost analysts develop the government's negotiating position in a sole source environment.

Table 1
Dual Source Missile Program Lot Data

Missile Program	Vendor	Total Missiles	Number Of Lots; Total And Dual Sourced	Units in Dual Sourced Lots	Number of Educational Buy Units	Total Cost From Vendor (discounted thousands of FY 83 $)	Total Cost From Vendor (non-discounted thousands of FY 83 $)
Sparrow (AIM-7F)	Total Dual Source	9,207	-	-	-	709,805	1,126,400
	Prime Source[1]	6,357	8, 4	5,432	-	532,363	824,857
	Second Source	2,850	6, 4	2,570	280	177,442	301,544
Sparrow (AIM-7M)	Total Dual Source	12,881			-	1,490,706	2,030,782
	Prime Source	8,859	6, 4	3,835	-	885,602	1,241,901
	Second Source	4,022	5, 4	3,312	710	605,104	788,880
Sidewinder (AIM-9L)	Total Dual Source	13,546			-	250,439	326,737
	Prime Source	8,192	5, 3	5,638	-	142,039	183,470
	Second Source	5,354	4, 3	4,434	920	108,400	143,267
Sidewinder (AIM-9M)	Total Dual Source	25,300			-	461,846	636,796
	Prime Source	13,597	6, 4	7,261	-	249,864	339,167
	Second Source	11,703	4, 3	10,503	1200	211,982	297,629

Footnotes:
1. The first lot's data for the AIM-7F was not used due to extraordinary production problems.

If the cost functions are to be estimated with contract level data and given the nature of these programs, degree of freedom problems are unavoidable. Three steps are taken here to mitigate the extent to which these problems effect the validity of the conclusions; 1) the rate elasticity, α, is estimated independently of the cost function parameters using "stepladder" bid data; 2) two techniques are used to estimate the remaining parameters (β and K); and 3) a "worst case" sole source cost curves is constructed.

Estimation of the Rate Parameter, α

In each annual lot competition, the split is a function of the firms' bid for each lot, but the bid mechanism is not the same for all programs. Often, a predefined split, e.g. 60 percent to the winner and 40 percent to the loser, is announced prior to the bidding. A mechanism that came into use in the mid 1970's was to require the bidding firms not just to specify a unit price for a lot, but rather what are called "step ladder" quotes; that is, a series of bids for a set of predefined splits of the total lot buy. In effect, these quotes trace out the firm's supply curve for the lot in question.

Table 2 summarizes the bid data that is available for each of the missile program's bid stages. Stepladder bid data was available for three of the missile programs, but not for the AIM-9L. The availability of these data permitted the direct estimation of the rate elasticity, α. The procedure includes the following steps:

1) For each program, a production rate of approximately half of the average total annual buys was identified. Stepladder bids at this rate (or approximately at it, since the pattern of the splits that quotes were requested on varied from lot to lot) were used to construct a constant production rate progress curve of the form (4) for each contractor in each program using the linear approximation methodology discussed in the next section.

2) The stepladder quote series for each vendor was transformed to series proportional to q^{α} using the estimate of β for each vendor from the previous step and inverting (6'), i.e.:

$$\ln \left\{ \frac{C(Q_i, q_i)}{\left[(Q_i + q_i)^{(1-b)} - Q_i^{(1-b)} \right]} \right\} = \ln \left[\frac{K}{1-b} \right] + \alpha \ln (q_i) + \varepsilon \qquad (7)$$

where ε is the error term. The resulting series was used to estimate α.

Table 2
Missile Program Supply Curve Data

Missile Program	Type of Contractor	Number of Lots	Total Number of Offers	Estimated Elasticity	t Statistic	R^2 Coefficient
Sparrow (AIM-7F)	Prime Source	4	35	-0.2310	-6.681	0.5750
	Second Source	4	35	-0.0926	-4.983	0.4294
Sparrow (AIM-7M)	Prime Source	3	9	-0.2321	-23.89	0.9879
Sidewinder (AIM-9M)	Prime Source	4	10	-0.3134	-8.494	0.9002
	Second Source	4	10	-0.4027	-8.043	0.8899
Pooled Regression Results	N/A	19	99	-0.2076	-12.563	0.8259

3) Since one program did not have stepladder quote data available, a weighted least squares regression was used to pool the data across contractors and programs to obtain an “average” rate elasticity.

The estimates of α obtained through this procedure are consistent with the values typically used by government cost analysts performing this type of analysis.

<u>Estimation of Progress Curve Parameters, K and β</u>

There remain two parameters, α and K, to be estimated for the sole source cost function (6’). The first step in estimating these parameters is developing a rate adjusted lot cost series from (6’):

$$C(Q,q)\ \ q^{\alpha}\ \ K\ \left[(Q+q)^{(1-\beta)} - Q^{(1-\beta)}\right] \equiv C_R(Q,q) \qquad (6'')\ ,$$

where C_R (Q,q) is the rate adjusted lot cost used to estimate the remaining cost curve parameters.

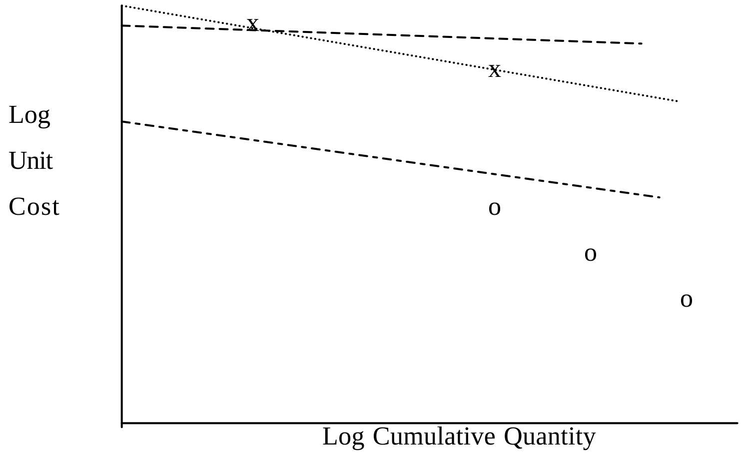
Three different approaches are used here in an attempt to bound the possible conclusions that can be reasonably reached with the data. They are:

1) nonlinear estimation using only the prime’s sole source lot data (closely analogous to procedures which would be used if government cost analysts were preparing negotiating positions in a sole source environment),
2) linear estimation over the entire set of production data with dummy variables to account for the presence of competition (uses all of the production data and has the least problem with the degrees of freedom), and
3) “worst case” construction (an attempt to construct, given each program’s initial lot’s cost data and a normative assessment of the government’s likely contracting procedures, what would be the most costly sole source outcome normally expected).

The three approaches were intentionally designed to cover the alternative possible conceptual approaches to inferring a sole source cost function from the data. The first approach is intended to be the point of view of a cost analyst, the second, an economist, and the third, a manager. For a hypothetical set of rate adjusted unit cost data (in logarithms) over a production run, figure 1 displays representative cost functions for each of the techniques.

Figure 1

Three Alternative Sole Source Curves



x - Lot Data Prior to Dual Source Competition

o - Lot Data of Dual Sourced Lots

……. Curve 1, Nonlinear Estimation

–·–·– Curve 2, Linear Estimation, Pooled Data

------ Curve 3, Worst Case Analysis

<u>Nonlinear Estimation using Sole Source Lots</u>

Cost analysts traditionally have estimated sole source cost functions by extrapolating from the prime firm’s lots prior to competition a “sole source” cost curve[10]. The rational for using only the prime lots prior to competition is that, under sole source, the cost data from these lots would be used to prepare the government’s (and the contractor’s) negotiating position. This approach doesn’t have a great deal to recommend it econometrically due to the very small (or absent) degrees of freedom in the estimation. Defense cost analysts typically use a linear procedure, similar to that outlined in the next section, to estimate this function. Nonlinear estimation is used here to reduce the amount of

Table 3
Sole Source Cost Functions
(Nonlinear Estimation)

Missile Program	Rate Elasticity	Estimated Cumulative Quantity Elasticity (β)	Estimated Constant Factor (K)	Mean Squared Error	Degrees Of Freedom	Discounted Estimated Sole Source Cost (thousands of FY 83 $)	Non Discounted Estimated Sole Source Cost (thousands of FY 83 $)
Sparrow (AIM-7F)	0.2311	0.1039	306.76	1464.7	1	622,588	1,024,553
Sparrow (AIM-7M)	0.2321	0.1050	349.38	5.71	1	1,062,945	1,508,633
Sidewinder (AIM-9L)	0.2076	0.0936	55.38	N/A	0	253,277	342,315
Sidewinder (AIM-9M)	0.3133	0.0835	59.77	N/A	0	304,190	428,169

manipulation that a linearizing procedure performs on the data. Given the lack of degrees of freedom in the data, these manipulations may significantly alter the results.

The estimation itself is reasonably straightforward. The prime firm's cost data for each of the lots prior to the advent of competition was used in conjunction with the a estimated above to minimize the mean squared error of relation (6') over K and β. Table 3 documents these results.

<u>Linear Estimation</u>

A second estimation was performed over the entire set of contract quotes by linearizing the lot cost data and using dummy variables to account for the contractor and the presence or absence of competition. The linearization procedure itself is directly analogous to procedures used by cost analysts. It defines a quantity, q_m, referred to as the lot midpoint, such that:

$$q_m = \left[(Q+q)^{(1-\beta)} - Q^{(1-\beta)}\right]^{1/(1-b)} \qquad (7')$$

With (6"), (7') yields a rate adjusted unit cost function of:

$$\frac{C_R(Q,q)}{q} = K\ q_m^{-\beta} \qquad (8)$$

Taking logs, (8) is equivalent to a linear reduced form of

$$\ln(C_R(Q,q)) = \ln(K) - \beta \ln(q_m) + \varepsilon \qquad (8') \quad ,$$

where ε is the error term.

Clearly, q_m, is dependent on the value of the β parameter. In practice, for values of β over a reasonable range, the estimate of the q_m's does not change a great deal. The midpoint is estimated (following cost analysis practice) by finding the β over an appropriate range of values that minimizes the mean squared error of (8).

A working hypothesis of this paper is the proposition that dual sourcing is economic. Consequently, the advent of dual sourcing should result in an alteration of the firm's cost curve parameters; i.e. β and K. Cost analysts refer to changes in the β parameter as a "rotation", and changes in K as a "displacement". Dummy variables D_K and D_β are included to provide for these changes. The final reduced form is therefore:

$$\ln\left(\frac{C_R(Q,q)}{q}\right) = \ln(K) - \beta \ln(q_m) + \delta_K D_K + \delta_\beta D_\beta \ln(q_m) + \varepsilon \qquad (9) \quad ,$$

where:

δ_K, δ_β - parameters, and

D_K, D_β - dummy variables for shift and rotation of the cost function (variables defined such that 0 is used for prime firm sole source lots).

The rate adjusted unit cost functional form of this model is then:

$$\frac{C_R(Q,q)}{q} = K \; qm^{(d_b D_b - b)} \; e^{d_K D_K}$$

The value of the prime firm's lot data required to estimate from (9) is straightforward. The value of the q_m's to be used with the follower's data is not as obvious. The purpose of the educational lots produced by the second source is to place that firm at the same point (with respect to underlying production costs) on the cumulative learning curve as the prime firm. The presumption is that the second firm, although having smaller cumulative total production history, will be able to meet the prime firm's price by virtue of the experience of these lots. Hence, the second source's q_m's are obtained from the prime firm's values for the corresponding lots. The second source's educational lots are thus not used in the estimation of the cost function, though the units are included as arguments to the cost function in the calculation of the sole source alternative total cost.

There is no necessary reason to assume that the two firms have an identical error structure in their cost function and falsely assuming so results in inefficient (though unbiased) estimators. Indeed, an F test on the significance of the difference of the error variance between the two contractors showed a significant difference for all programs. Consequently, an estimated generalized least squares[11] (EGLS) was used to permit the error term to differ among contractors.

Table 4 documents the results of the linear estimation. It is obvious from form (9) that multicollinearity among the variables D_K, $\{D_p \ln(q_m)\}$, and $\ln(q_m)$ is likely to be a problem. This problem does not bias the estimated parameters, but does result in larger parameter variances. From

Table 4
Sole Source Cost Functions
(Linear Estimation)

Missile Program	Estimated Cumulative Quantity Elasticity (β)	Estimated Constant Factor (K)	Estimated Rotation Factor (K)	Estimated "Shift" Factor	Mean Squared Error (thousands of FY 83 $)	Degrees Of Freedom	Discounted Estimated Sole Source Cost (thousands of FY 83 $)	Non Discounted Estimated Sole Source Cost (thousands of FY 83 $)
Sparrow (AIM-7F)	-0.1271 (-2.920)	359.38 (21.28)	-0.2846 (-3.840)	2.1451 3.775	6.26	7	595,780	975,073
Sparrow (AIM-7M)	0.1094 (-1.325)	360.25 (11.79)	0.0402 (-0.317)	0.2520 0.262	14.04	5	1,052,395	1,492,584
Sidewinder (AIM-9L)	-0.0902 (-0.688)	53.93 (4.373)	-0.2271 (-1.067)	1.6860 0.990	2.37	4	214,630	289,821
Sidewinder (AIM-9M)	-0.0816 (-1.484)	58.76 (10.25)	-0.3052 (-3.936)	2.5495 4.039	1.42	6	363,180	512,231
Restricted Estimation								
Sparrow (AIM-7M)	-1390 (-5.05)	425.76 (27.36)	N/A	N/A	12.56	7	947,055	1,336,562
Sidewinder (AIM-9L)	-0.2332 (-4.58)	142.26 (11.89)	N/A	N/A	2.52	6	149,367	197,841

the standpoint of the significance of the parameter t tests, this problem applies to the AIM-7M, AIM-9L and AIM-9M. At the risk of model misspecification (which does bias parameter estimates and leads to inconsistent estimation), common defense cost analysis practice is to drop the statistically insignificant terms, in a manner similar to "stepwise" regression. This was also done (using EGLS, as above) for the three "problem" programs, with the results displayed at the bottom of table 4. These results are not considered further since they are econometrically flawed and the cost functions based on them yield astronomically high additional cost from dual sourcing (greater than 50 percent, discounted, as measured by equation (1), for all three programs [12].

Worst Case Sole Source Estimates

It has been asserted that analysis similar to that done above is biased against dual sourcing being cost effective since the prime firm will anticipate the effects of head to head competition prior to the advent of dual sourcing and price its lots prior to competition lower than would be the case if the same firm was producing under a pure sole source arrangement. This anticipatory phenomenon, it is asserted, combined with the very small samples and, hence, the significant influence that each lot's cost has on the resulting cost function causes a significant downward bias in the resulting estimated sole source cost structure. Indeed, anecdotal evidence tends to support the existence of such a phenomenon. The Navy's HARM missile (which, ultimately, did not become a dual sourced program) is a case where program personnel ascribe the prime firm's behavior clearly to the threat of competition. However, the economic motivation behind such actions is unclear since a firm might choose to raise its prices prior to dual source competition in order to capture rents presumably removed during competition.

While the thrust of this argument is irrefutable empirically, I constructed a worst case sole source analysis to test the reasonableness of this proposition. The worst case analysis is predicated on two propositions: that the cost of the initial production lot is determined primarily by technical characteristics of the missile and that the progress curve elasticity (i.e. β), without rate adjustment (i.e. $\alpha = 0$), of tactical missiles is no less than 0.1520. (Cost analysts commonly refer to elasticities units called "percent slope", or 100 minus the percent change for doubling the quantity. The value of 0.1520 corresponds to a 90 percent slope.) The first proposition is supported by the fact that engineering considerations and changes to the TDP are normally dominant features of the first production lot. To the extent that this is true, there should be relatively little opportunity for competition related factors to determine the costs. The second proposition is consistent with the assumptions and experience of government cost estimators. The flattest progress curve slope (with no rate adjustment) normally encountered in tactical missile programs is an elasticity of 0.1520. Using

Table 5
Sole Source Cost Functions
(Worst Case Analysis)

Missile Program	Rate Elasticity (α)	Estimated Cumulative Quantity Elasticity (β)	Estimated Constant Factor (K)	Discounted Estimated Sole Source Cost (thousands of FY 83 $)	Non Discounted Estimated Sole Source Cost (thousands of FY 83 $)
Sparrow (AIM-7F)	0.0	0.1520	460.5	633,920	1,058,741
Sparrow (AIM-7M)	0.0	0.1520	600.8	1,288,190	1,833,640
Sidewinder (AIM-9L)	0.0	0.1520	84.4	199,033	268,973
Sidewinder (AIM-9M)	0.0	0.1520	95.1	363,530	514,913

this elasticity, the lot midpoints derived above and the cost of the first lot (at the request of program personnel, the third lot of the AIM-7F was used for this purpose), a constant K is derived from relation (4). Table 5 documents the results.

Comment on Savings Analysis

With all three of the above methodologies, the cost functions estimated for the sole source were evaluated using as arguments the profile of the total (prime and follower) annual lot buys to generate both discounted and nondiscounted sole source costs (TC_{SS}). Following DoD practice, the discount rate used is 10 percent annually. These values are shown in the final columns in Tables 3, 4 and 5. They were used in calculating the savings percentages shown in Table 6. Only in the case of the AIM-9L with nonlinear estimation, did the analysis show even slight savings to the government (just over one percent savings on present value basis). Even for this program, the results were negative for the other two techniques. These results are not unique (for missile programs) and other sources (Greer and Liao[8], and Beltramo[2]) have had similar results for this class of systems.

This conclusion is partially a result of the nature of missile technical innovation. If the AIM-7F missile program included a substantial portion of the units that were built in the follow on AIM-7M model, dual sourcing would have been profitable. The follow on missile models are driven by both technology (the availability of new circuits) and the threat (advances in jamming capabilities). Indeed, while not included here, a similar analysis for the Tomahawk program, but using extrapolated dual source cost functions for the remaining seven production lots, indicates that that program will approximately break even on a present value basis. This conclusion about the Tomahawk rests on not only the accuracy of the assumed dual source cost functions, but also on the assumed size of the total buy.

Evidence such as this has been criticized on the basis of prime firm anticipatory pricing discussed earlier. The presence of the threat of competition, so the argument goes, imply that no type of cost function estimation with empirical data is capable of measuring the “actual” cost that the government would have had to pay under sole sourcing. Given the validity of this proposition, an interesting question to ask is what would be the magnitude of the prime firm’s cost curve shift required to achieve this behavior (assuming in the absence of the anticipation of competition, the sole source cost function was sufficient to just breakeven as compared to dual sourcing)? Assuming that the anticipation phenomenon is entirely composed of a vertical displacement in the cost curve, trivial manipulation of (1) will show that the percentages in figure 6 are precisely the magnitudes of the required shifts. Whether shifts of the magnitudes indicated in table 6 are likely in response to the

Table 6

Percentage Present Value Savings / Cost

Missile Program	Sparrow (AIM-7F)	Sparrow (AIM-7M)	Sidewinder (AIM-9L)	Sidewinder (AIM-9M)
Discounted:				
Linear Estimation	-19.1 %	-41.7 %	-16.7 %	-10.9 %
Nonlinear Estimation	-14.0 %	-40.2 %	1.1 %	-32.4 %
Worst Case	-12.0 %	-15.7 %	-25.8 %	-10.8 %
Non-Discounted:				
Linear Estimation	-15.5 %	-36.1 %	-12.7 %	-3.9 %
Nonlinear Estimation	-9.9 %	-34.6 %	4.6 %	-24.3 %
Worst Case	-6.4 %	-10.8 %	-21.5 %	-3.3 %

threat of competition is a matter of speculation. Nonetheless, by construction, shifts of these magnitudes are sufficient only for breaking even as compared to dual sourcing; actual savings from dual sourcing would require proportionately greater shifts.

Conclusions

Tactical missiles represent a class of weapons systems in which there has been a strong presumption that dual sourcing saves the government money. Constructing the estimate of the sole source cost is the fundamental problem of any study of dual sourcing savings. The estimation problem is compounded by the small samples that are inherent in the data. In this study, using two substantially different types of statistical techniques, savings from dual sourcing as compared to sole sourcing were not (except for a single case) found. In addition, the worst case analysis shows that, given a plausible sole source cost function (that is constructed from “worst case” sole source experience), there is still no savings to dual sourcing. This study only analyzed contractor costs (both recurring and nonrecurring), and, as such, ignored other in-house government costs associated with dual sourcing, such as additional management, testing, and quality control costs.

Program managers have often remarked on the beneficial effect, in terms of vendor responsiveness and, particularly, quality, that dual sourcing has. Dual sourcing clearly diversifies the “industrial base” (i.e. the potential industrial suppliers to DoD). These benefits are accompanied with some additional nonprocurement related burdens to the government; primarily potential logistical problems with two, not necessarily completely interchangeable, fielded systems. Dual sourcing of tactical missiles may be advisable on balance, but its benefits appear to be nonmonetary arid should be clearly weighed against what appear to be, for tactical missiles, uniformly higher costs.

Appendix A
Comments on Individual Programs

Missiles are normally produced in several parts, typically the motor, warhead and guidance and control assembly. The final mating of the various subcomponents is done at a government facility. The guidance and control assembly is the most expensive and complex portion of most tactical missiles.

Sparrow AIM-7F (Guidance and Control Assembly)

This was the first of the contemporary dual source programs, originally being produced in the 1975. The Sparrow itself is a relatively complex semi active radar guided air to air missile. The 7F variant represented a large break with previous versions since it was entirely solid state. There were significant initial configuration problems configuration problems with the initial missile design, but they were resolved prior to the advent of second sourcing. The bid data of the two contractors' after the advent of competition clearly show a pattern of "strategic pricing". One of the contractor's had difficulty performing on a single year's lot when a large split was awarded. The initial lot was produced in fiscal year 1980. At the request of program personnel, he first lot's data was not included in the estimation due to extreme technical problems with the missile. Since the first lot's data could not be used, and the second lot also had problems, the worst case sole source curve's parameters were based on the cost of the third lot.

Sparrow AIM-7M (Guidance and Control Assembly)

The AIM-9M is a follow on to the 7F Sparrow. It has an all digital seeker and an advanced monopulse design. Substantial configuration and performance problems were encountered in an initial lot from the second source that were attributed to a change in location of the production facility. Final lot will be acquired in fiscal year 1987, and data on this lot was not available for analysis. There are substantial foreign sales of this missile in the final year of production and unit costs would be altered considerably by virtue of this fact.

Sidewinder AIM-9L (Guidance and Control Assembly)

The Sidewinder is a relatively simple passive IR missile, but the 9L represented a very significant (and expensive) upgrade from its predecessor, the AIM-9B. The complexity of the 9L is due to the incorporation of "all aspect" engagement capability. Final lot was acquired in fiscal year 1980.

Sidewinder AIM-9M (Guidance and Control Assembly)

The 9M is an upgrade of the 9L, primarily in the area of the missile's electronics, as well as an advanced seeker. It is not as large a change as the 7M was to the 7F. The 9M is currently planned to have at least one more lot, but the quantity will not be great enough to keep two contractors producing the missile.

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Footnotes

1. Dual sourcing has become sufficiently popular with Congress that a provision in the FY1986 Authorization act specifically states the Secretary of Defense must certify to Congress the reasons that the department does not intend to dual source a new system. The certification must be made prior to Full Scale Development, normally three years or so prior to production. This means that the certification must be made prior to the point at which design issues, that bear directly on the economic suitability for dual sourcing, have been resolved, or even completely identified.

2. Berg, R., "The Analysis of Competition in Defense Acquisition", Center for Naval Analysis, 1986, page 14

3. The two most commonly cited studies, Daly, et al[5] and Drinnon and Hiller [6], have 66.7 and 60.1 percent of their examined cases in the electronics category and most other studies have similar percentages. The preponderance of electronics as examples in dual sourcing analyses appears to stem from two factors; that the DoD buys a large number of different types of electronics systems and that electronic fabrication and assembly production assets are reasonably fungible (as compared to, for example, aircraft production assets).

4. The problems in methodology are illustrated by the fact that two of the most comprehensive studies, Daly, et al[5] and Drinnon and Hiller [6], analyze 27 systems using the same data, but the correlation between the estimated savings percentages between the two studies is 0.497. This value, though not a particularly high correlation coefficient, is significant.

5. Hampton, Richard J., "Price Competition in Weapons Production: A Framework to Analyze Its Cost-Effectiveness", Air University Press, 1984, page 78 and Table 3-9 on page 62.

6. In a prepared statement submitted as testimony related to the DoD Fiscal Year 1986 Appropriations Act, the Assistant Secretary of the Navy for Research, Engineering and Systems, the Honorable Melvin Paisley, specifically cited the Navy's savings from the dual sourcing of tactical missiles as evidence of the efficacy of dual sourcing as an acquisition strategy.

7. Beltramo, M. J. "Dual Production Sources in the Procurement of Weapon Systems: A Policy Analysis", The Rand Graduate Institute, 1983, page 106

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9. Within the defense community there is some difference of opinion on the effects of production rate changes on unit costs. Balut, S. J., "A Method for Estimating Learning and Rate Effects in Military Aircraft Procurement Programs", Institute for Defense Analysis, presents an opposing view.

10. Other studies using essentially this approach include Beltramo[2] and Zusman, et al[11].

11. Judge, et al, The Theory and Practice of Econometrics, pages 428 to 430.

12. A related question is what, if anything, is the effect of the advent of competition on the cost functions? The joint null hypothesis for this test is that $\delta_K = \delta_\beta = 0$. An F statistic to test the hypothesis was insignificant at the 95 percent level for all four programs. This is likely not to be a particularly strong result due to multicollinearity's effect on the efficiency of the estimators.